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PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Improvements in methods and apparatus for Electrically Perforating Dielectric Materials

We, MEYER LABORATORIES., INC., a corporation organized and existing under the laws of the State of Connecticut, United States of America, and having a place of business at North Haven, Connecticut, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to methods and apparatus for electrically perforating dielectric materials, and is primarily concerned with piercing optical contact lenses in order to ventilate the surface of the eye beneath the contact lens. The invention is also applicable to the manufacture of certain kinds of filter.

The provision of very small pores or holes at selected points in contact lenses has been attempted heretofore with limited success as a technique for overcoming physiological problems encountered in correcting deficiencies in sight by means of lenses which contact the cornea of the eye. Some of the clinical purposes in perforating such lenses are:

(1) to avoid mechanical corneal irritation by allowing the practitioner to fit lenses with less movement during use than might otherwise be required;

(2) to achieve substantial ventilation of the cornea;

(3) to make possible large optical zones in the lenses when desired;

(4) to allow the use of larger lens diameters when desired;

(5) to increase the stability of the lens;

(6) to provide adequate relief in fitting cosmetic lenses;

(7) to make possible the use of contact lenses in cases where the corneas are irregular, such as Keratocanus, or where irregular astigmation is present resulting in blocking of fluid;

(8) to relieve physiological problems produced by the thickness of the lens;

(9) to increase the possible wearing time of the lenses; and

(10) to maintain a cornea-lens relationship in therapeutic use of contact lenses.

Perforations are desirable in contact lenses in order to provide adequate lacrimal flow in the retro-lens space so that gaseous materials may be transmitted through the lens and heat dissipated. In addition, such perforations eliminate microscopic air bubbles behind the lens and provide a more adequate supply of oxygen to the areas of the cornea under the lens.

Methods have been devised for forming microscopic holes in contact lenses. For example, extremely fine mechanical drills have been employed. However, these methods have not been entirely satisfactory due to the difficulty of formng holes of suitable quality, especially with respect to the formation of holes without detrimental surface defects either in the walls of the holes or on the surfaces of the lenses surrounding the holes.

Certain criteria have been found to be necessary for high quality perforations or ventilating holes in contact lenses. For example, the hole should be straight; it should be normal to both lens surfaces — or at least as nearly normal thereto as the geometry of the lens permits; the walls of the hole should be as smooth as the surfaces of the lens and should not be discoloured; the area surrounding the hole should contain minimal fracture lines or other irregularities and should not be darkened by excessive heat generated during the perforating process; the diameter of the hole should preferably be smaller than 0.10 mm. or 0.0039 inches; and there must be total freedom from even microscopic burrs or protrusions at either surface of the lens due to the formation of such hole.

If these criteria are not closely adhered to, various adverse effects on the wearer of the lens may occur. If the holes are too large

or are not disposed with their axes normal to the surfaces of the lens,, and if protrusions are present around the holes in either surface of the lens, abrasion of the cornea and/or of the eyelid of the subject may cause considerable discomfort. Also where the diameter of the hole is too large, vision may be disturbed by the hole itself or by excess accumulation of fluid on the outer surface of the lens. Moreover the holes may become clogged if they are not straight or if their walls are not adequately smooth.

From the foregoing it will be apparent that great care must be taken in perforating contact lenses to produce holes which will not result in problems that are more troublesome than those they are intended to overcome.

An object of the present invention is to produce holes or perforations which are of accurately predeterminable size and which may be placed at close or wide spacings and at any desired location on the object being perforated.

Another object is to provide means by which the article to be perforated may be quickly and easily moved from one position to another relative to the device which perforates it, so that the holes can be made at the desired locations while ensuring that each hole, regardless of its location, is directed along a line which is normal to the surface where the hole is located.

According to the present invention the article to be perforated, such as a contact lens, is placed between a pair of electrodes which are then brought into engagement with the surface of the article. A predetermined mechanical pressure is then applied on the article by the electrodes, which are then fixed while an electric current is discharged for a given interval of time between the electrodes in order to form a clean hole of desired diameter through the article.

Locking of the electrodes engaging the article prevents their movement into the hole which is formed and thus serves to prevent enlargement of the hole or damage to the article, as well as to the electrodes in some instances.

In practice it hs been found desirable to perform the electro-piercing operation under a dielectric fluid which ensures that the current travels directly through the article rather than over its surface and permits holes to be pierced in close proximity to each other.

Apparatus embodying the invention includes a work-holder for positioning the article or workpiece, which may be in the form of a leaf of dielectric material relative to an electrode, together with means, such as a spring in the electrode-assembly, for urging the electrode and workpiece into engagement with each other under a predetermined force. Means are also provided for fixing the electrode and workpiece against further movement together and for discharging an electric current through the workpiece for a given time-interval in order to perforate the workpiece.

Two electrodes are desirably arranged coaxial with each other with the workpiece between them in the workholder. The upper electrode is first brought into engagement with the workpiece and pressed firmly against its holder. A set-screw or similar locking means is used for fixing the electrode in its holder after it has been brought into pressure-engagement with the workpiece, thereby preventing the electrode from being forced into the hole when it is formed. After the upper electrode is locked in engagement with the workpiece, the lower electrode is brought up into engagement with the underside of the workpiece and also locked in place. In order to form straight holes as small as 0.0039 inch in diameter or smaller, it is essential that the ends of both electrodes be sharply pointed and disposed directly opposite each other.

One practical embodiment of the present invention as applied to the formation of holes in contact lenses, will now be particularly described by way of illustration only with reference to the accompanying drawings in which:

Figure 1 is a side view, partially broken away and in section, of the electrode holder assembly;

Figure 2 is a view similar to Figure 1, but showing the electrodes in position to receive a workpiece in the work-holder;

Figure 3 is a perspective view, partially broken away and in section, of one of the electrode assemblies;

Figure 4 is an enlarged view in vertical section through the lower holder arm and electrode assembly;

Figure 5 is a purely schematic drawing on a greatly enlarged scale illustrating how a contact lens is held with respect to the electrodes in order to place the holes in the lens at any desired point on the lens while ensuring that the hole will always be normal to both surfaces of the lens;

Figure 6 is another purely schematic view of the tips of the electrodes as they would appear under a microscope just after a hole is formed in the workpiece illustrating the approximate relation of the hole to the electrode tips;

Figure 7 is a circuit diagram of the electrical system which furnishes the current to the electrodes for perforating the workpiece; and

Fig. 8 is a diagram of a portion of the circuit shown in Fig. 7 in which a modificatin is incorporated.

Apparatus embodying the invention as shown in the drawings includes an electrode holder assembly (best shown in Figs. 1 and 2), which is firmly mounted on a base 10 and comprises a lower horizontal forwardly extending holder arm 12 and an upper holder arm holder arm 14 disposed parallel to the

arm 12 and spaced therefrom by means of a vertical post 16 located adjacent the rear ends of the holder arms 12 and 14. Near the front ends (to the right as viewed in Fig. 1) of the holder arms 12 and 14 are provided axially aligned, vertical holes 18 and 20, respectively, which receive and hold a pair of oppositely facing, elongated electrode assemblies 22.

As is best shown in Fig. 3, the electrode assemblies 22 each consist of an outer sleeve 24 and a sharply pointed electrode 26, which is slidably supported within the bore 27 of the sleeve 24 and is resiliently urged toward one end of the sleeve 24 by a compression spring 28 located in a slightly enlarged chamber 29 at the opposite end thereof. The spring 28 presses against a head 30 of the electrode 26, which fits within the chamber 29 and is compressed by an adjusting screw 32 threaded into the outer end of the sleeve 24. The head 30 of the electrode 26 engages a stop shoulder 31 formed between the bore 27 and the chamber 29, thus limiting the axial travel of the electrode under the pressure of the spring 28. A needle-like tip 33 is desirably separable from the body of the electrode 26 so that it can be removed and be replaced as its point wears. To this end the tips 33 may be press-fitted into a socket provided in the end of the body portion of the electrode 26.

An elongated slot 34 extends axially of the sleeve 24 in one side thereof in order to permit access to the electrode 26 by either of two locking screws 36 threaded through the outer ends of each of the holder arms 12 and 14, respectively. The locking screws 36 fix the electrodes 26 in the desired position as will be described hereinafter.

A work-holder or lens cup 38 is removably mounted on the upper surface of the lower holder arm 12 at the forward end thereof. The work-holder 38 is a cup-shaped member having a cavity 39 in its upper surface, in which is placed a contact lens *w* to be perforated. The bottom surface 40 of the cavity 39 is desirably a spherical, concave surface, with its radius of curvature substantially equal to that of the convex surface of the lens, and with its centre of curvature located on the longitudinal axis X—X of the electrodes 26. It will be noted that the lens can be shifted to the desired position between the tips 33 of the electrodes 26, in order to form a hole in any desired location in the lens. Moreover, as will be seen in Figures 5 and 6, the axis X—X of the electrodes will always be normal to the convex surface of the lens regardless of the point at which the hole is to be formed. This ensures that the hole will be substantially normal to both the inner and outer surfaces of the lens, disregarding of course any slight differences in curvature of the surfaces of the lens. (Throughout this specification, the expression "normal to the (or both) surfaces of the lens" is to be understood in the context of this proviso).

A vertical hole 42 (Figure 4) is provided in the centre of the lens cup 38, through which the conical tip 33 of the lower electrode 26 extends upwardly into engagement with the underside of the lens *W*. Since the perforation is made under a dielectric fluid *F* contained in the lens cup 38, it is necessary in order to prevent leakage of the fluid from the cup to have a close sliding fit between the sleeve 24 of the electrode assembly 22 and the walls of the hole 18 in the holder arm 12 and between the electrode 26 and the sleeve 24. On the other hand, the tip 33 of the lower electrode 26 fits relatively loosely within the hole 42 so that fluid in the lens holder 38 is permitted to flow through the hole 42 around the tip 33, as shown in Fig. 4 for the purpose of insulating the lower electrode. In order to centre the lens holder 38 with respect to the axis of electrodes 26, a circular boss 43 is provided on the under surface of the holder 38 concentric with the hole 42. When the lens holder is placed in position on the lower holder arm 12, the boss 43 is received within a precisely fitting recess in the upper surface of the arm 12 concentric with the hole 18 in which the lower electrode assembly 22 is held.

If desired, the bottom surface 40 of the cavity 39 in the lens holder may be convex, rather than concave as shown, in which event the lens would be inverted so that it concave surface faces downwardly in order to conform with the curvature of the bottom of the cavity 39 in the lens holder. It has been found, however, that in manually positioning the lens in the holder and removing it after the piercing operation is completed, the lens can be more readily handled when the bottom surface 40 is concave as shown in the drawings. In order to further facilitate removal of the lens from the holder 38, the upper walls 44 of the cavity 39 may be provided with a curvature different from the bottom surface 40, thereby forming a ridge 46 at the intersection of the walls 44 and the bottom 40. In order to remove the lens from the cup; it is simply moved across the bottom surface 40 until the edge of the lens projects over the ridge 46 so that the lens may be readily grasped with a pair of tweezers or similar implement.

Referring again to the electrode assemblies 22, it will be noted in Fig. 1 that an outer spring 48 encompasses the sleeve 24 of each electrode assembly outwardly of the holder arms 12 and 14. A brass or copper washer 49, to which an electrical conductor may be connected for supplying power to the electrode, as disclosed hereinafter, fits around the sleeve 24 of each electrode assembly next to the outer sides of the holder arms. The springs 48 are compressed between the washers 49 and nuts

50 threaded on the outer ends of the sleeves 24 of the electrode assemblies 22. The springs 48 urge the electrode assemblies 22 outwardly or in opposite directions from each other to their retracted position. When the locking screws 36 are released from rigid engagement with the electrodes 26, the outer spring 48 provided on each electrode assembly draws the electrode out of engagement with the workpiece. Such outward movement of the electrode assemblies 22 is limited by the screws 36, the ends of which remain within the slots 34 in the sleeve 24, so that as each of the locking screws is loosened, the electrode automatically retracts to the position shown in Fig. 2. The lens *W* is then free to be moved in its holder so that another perforation can be made at any other point on the lens or, if all the perforations required have been made, the lens can be removed and cleaned.

It will be noted that the electrode assemblies are normally held in the holder arms 12 and 14 where they can be readily moved in contact with a lens in the holder 38. Both electrode assemblies are identical except that the upper one is longer so that it can be retracted to a position above the lens holder 38. When it is desired to remove either or both electrodes entirely from the apparatus in order to resharpen or replace its tip 33, the locking screws 36 may be slackened far enough so that their ends clear the slots 34 in the sleeves 24, thus permitting each electrode assembly 22 to be removed as a unit. The tips 33 can then be easily removed from the shanks 26 and replaced with sharp tips.

In perforating a contact lens in accordance with the present invention, the electrode assemblies 22 are located in their retracted positions as shown in Fig. 2 with the locking screws 36 loosened so that the electrodes 26 and sleeves 24 are free to move longitudinally with respect to the holder arms 12 and 14. The lens *W* is then placed on the bottom surface 40 of the lens holder 38 so that the tips of the electrodes may be brought into engagement with the lens at the proper point where a perforation is to be made. A sufficient quantity of dielectric fluid *F* is placed in the cavity 39 of the lens holder 38 so that the lens is completely immersed. Fluid *F* is desirably placed in the holder 38 before the lens in order to ensure that the fluid flows through the hole 42 to insulate the lower electrode 26. A film of insulating fluid also separates the under surface of the lens from the bottom 40 of the lens holder. The dielectric fluid employed should be one which has a fairly low viscosity and which does not readily break down under extreme temperatures. It has been found that a silicone dielectric fluid produced by General Electric Company identified as XF—1053 is highly satisfactory for this purpose. The viscosity of XF—1053 is 140 CS. at —80°F and 2 CS. at 400°F. This fluid has a flash point of about 450°F and a dielectric strength of 32.5 KV. It has sufficient healing power to maintain its dielectric strength after repeated applications of current, thus making it unnecessary to replace the fluid even when a large number of perforations are being made at a time.

The upper electrode 26 is first brought into engagement with the upper surface of the lens by pressing the assembly 22 downwardly against the pressure of the retracting spring 48. When the tip 33 of the elctrode contacts the surface of the lens, further movement of the electrode 26 itself is arrested, and the desired pressure of the tip 33 against the lens is then obtained by moving the sleeve 24 down an additional amount, so that the head 30 of the electrode 26 is lifted off its stop shoulder 31 against the pressure of the compression spring 28. In this way a predetermined amount of pressure of the electrode 26 can be exerted against the surface of the lens. When the desired pressure of the upper electrode on lens *W* is obtained, the locking screw 36 is tightened against the electrode 26, thereby fixing the latter and its sleeve 24 in place. The pressure of the electrode is therefore maintained against the surface of the lens.

With the upper electrode pressing the lens *W* downwardly against the bottom 40 of the lens holder 38, the tip of the lower electrode is brought up through the hole 42 in the bottom of the holder 38 into engagement with the under surface of the lens and pressure is applied in the same manner as when the upper electrode is brought into its working position. In order to ensure that the lens is not lifted off its supporting surface 40, the pressure applied by the lower electrode should be no greater than that exerted by the upper electrode. The pressure of the lower electrode 26 on the lens is then maintained by tightening its locking screw 36, and the apparatus is ready for the perforation to be made by impressing a high voltage on the electrodes, causing an electrical discharge between them and through the material of the lens *W*.

As may be seen in Fig. 6, the tips 33 of the electrodes 26 are not forced into the hole formed in the lens by the piercing operation. This is due to the fact that both electrodes are fixed in place by the locking screws 36. It will be appreciated that the lens material in the immediate vicinity of the hole formed will become softened somewhat by the electrical discharge and that serious damage to the lens could be caused by the electrodes if they are permitted to continue to exert pressure against the lens while the perforation is actually being made. The electrodes, however, being fixed in their holders 12 and 14 by the locking screws 36, are positively prevented from pressing into the surface of the lens, thereby forming a clean right-angle intersection of the hole at each surface of the lens.

When the hole has been formed, the locking screws 36 are loosened to allow the retracting springs 48 of the electrode assemblies 22 to withdraw the assemblies from the lens to the positions shown in Fig. 2. The lens can then be shifted in its holder and one or more additional holes formed in the same manner. An important advantage of the present invention is that it makes possible the placement of holes at extremely close proximity to each other on the workpiece being perforated. For example, it has been found that each hole may be located as close to an adjacent hole as the size of the holes involved. In other words, if the holes being pierced are 0.003 inches in diameter, they can be spaced as close as 0.003 inches to each other by using the perforating technique of the present invention. If need be, smaller holes can be located even closer together. It is believed that this is made possible by the presence of the dielectric fluid in the openings of the existing holes while the new holes are being formed, and by pressure-engagement of the electrodes on opposite surfaces of the material being perforated, thus ensuring that the line of least electrical resistance is a straight line through the material between the points of the electrodes rather than through holes already pierced in the material. It will be appreciated that this is an important advantage, not only in the perforation of contact lenses, but also in other applications, such as in the manufacture of extremely fine filters.

It is important to bear in mind that in order to obtain a hole through the lens which is normal to the curvature of the lens, the sharp points of the electrodes must be directly opposite each other. In order to accomplish this, it is necessary that the points on the tips 33 be accurately machined and that the holes 18 and 20 in the holder arms 12 and 14 be perfectly aligned. Furthermore, the sleeves 24, electrodes 26 and tips 33 of the electrode assemblies 22 must be exactly concentric with each other in order to ensure that the points of tips 33 lie precisely on a line normal to curvature of the lens. In order to avoid any eccentricity of the tips of the electrode, an alignment bar should be placed in the holes 18 and 20 of the electrode holder assembly before the electrodes are assembled in position, and the holder arms 12 and 14 adjusted by suitable means (not shown) until the holes 18 and 20 line up perfectly. If any eccentricity is still found to exist, the electrodes 26 may be rotated in their sleeves 24 to bring the points of tips 33 into exact alignment.

Power is furnished to each electrode 26 through suitable conductors 52 connected to the washers 49, against which the retracting springs 48 are compressed. Conductors 52 are run along the outer surfaces of the holder arms 12 and 14, respectively, to terminals 54 located at the back ends of the holder arms.

Referring now to the wiring diagram of Fig. 7, power is supplied from a standard 110-volt, 50 cycle, supply line through a cut-off switch 60 to an electronic timer 62 of suitable type. An indicator light 64 is provided in the power supply in order to indicate when the power is on. Suitable connections are made at timer 62 with the power supply in order to select the desired time interval during which power is fed to the electrodes for perforating a workpiece. A push-button switch 66 is provided on the timer for initiating the time cycle. A voltage control 68, such as a "Powerstat" Type 20 or similar unit, is connected by leads 70, 72 across the primary of a first step-up transformer 74. The input to the control 68 is provided by a power lead 76 connected to one side of the 110—V power main and a lead 78 from the timer 62. A diode rectifier 80 is placed in one of the primary winding leads for a purpose to be described presently. The secondary of the transformer 74 is tapped to provide different output voltages which may be selected by the voltage selector 82. The voltage thus selected is fed to the primary of a high-tension transformer 84, and again a diode rectifier 86 is provided in the primary circuit of this second transformer. High voltage output from transformer 84 is supplied through leads 88, 90 to the terminals 54 of the electrode holder assembly.

The diodes 80 and 86 in the primaries of the respective transformers control the type of discharge produced at the electrodes so that shattering of the lens is prevented.

The arrangement of two step-up transformers here disclosed provides certain advantages of flexibility in voltage selection and control, as well as greater availability of transformers suitable for the purpose. A single transformer of proper step-up ratio could, however, be substituted for the arrangement specifically illustrated and described.

With the electrode assemblies 22 in proper engagement with a lens *W* as hereinbefore described, and with the power supply switch 60 closed, the timer push-button switch 66 is actuated to start the perforating cycle. A high-voltage current of predetermined duration is thus discharged between the tips 33 of the perforating electrodes.

It has been found that the size of the hole produced depends primarily on the current or amperage of the discharge at the electrodes, and within reasonable limits as indicated hereinafter, changes in voltage and in the length of time that the power is applied to the electrodes has little significant effect. Moreover, from tests conducted it appears that small differences in the thickness of the material being perforated do not produce any noticeable change in the size of the aperture. Thus, it is entirely pactical, in lenses which do not vary too greatly in thickness, to produce per-

forations of substantially uniform size without changing the voltage or time interval of the electrical discharge.

Holes produced in accordance with the above described process form right-angle junction with both lens surfaces; that is, the surface junction are free of bevels, blends or other deviations, such as microscopic burrs or protrusions. Moreover, the axis of the hole is normal to the surface of the lens, the inner walls have a high quality finish, and fracture lines surrounding the holes or perforations are minimal.

In the following tables the results obtained in the course of perforating a number of contact lenses under different operating conditions are indicated. These tests were performed on contact lenses of standard optical-quality methyl methacrylate co-polymer sold under various trade names such as "Electroglas No. 2", "HyFrax" and "PMMA". "Electroglas" is a product of Glasflex, Inc., of Sterling, New Jersey, which has a dielectric constant of 2.73 at a current frequency of one megacycle. In each sample tested the electrodes exerted a pressure of approximately $1\frac{1}{8}$ oz. on the lens surface before the perforation was made.

Table *A* shows perforation or hole diameter versus electrode voltage, the lens thickness and the time interval of discharge being kept constant. In these examples the lens thickness in each case was 0.25 mm. and the interval of time of the electric discharge was 0.02 second. In this and in all other examples hereinafter mentioned, the XF—1053 dielectric fluid previously mentioned was employed.

TABLE A

Approx. High Tension Transformer Output Voltage	Diameter of Hole in Inches	
	Sample 1	Sample 2
2,360	0.0030	0.0035
4,720	0.0036	0.0032
7,090	0.0033	0.0032
9,450	0.0035	0.0031
11,810	0.0032	0.0031
15,090	0.0030	0.0029
16,535	0.0035	0.0035
18,890	0.0031	0.0034
21,275	0.0039	0.0035
24,860	0.0029	0.0033
26,590	0.0033	0.0034
28,335	0.0035	0.0036

The high tension transformer, corresponding to the transformer 84 in Fig. 7, used in obtaining these results was energized by 60-cycle alternating current and had a nominal output rating of 15 kv. at 60 milliamperes. The transformer was actually operated at voltages above its nominal rating in some instances, principally for purposes of test. However, the period of operating under overload condition is so short (only a fraction of a second) in each instance that no damage results, although a transformer having an adequately high insulation rating should obviously be employed.

At the extreme lower and upper voltages noted in Table *A*, the holes produced in the lenses are poor. Incomplete perforation or irregularity in the wall of the hole results at the low voltage end, while burning, flashing and/or cracking of the lens occurred near the upper limit of the voltage range. In between these extremes, however, the results are good, the holes produced being free of cracks, craters, flash-marks or other irregularities. But variation of the voltage at the elctrodes, within

the range indicated, appears to have no significant effect upon the diameter of the hole produced. This is further evidenced in Table *B*, which is a tabulation similar to that in Table *A*, but in which a different high tension transformer was used, having a nominal rating of 10 kv. at 24.2 milliamperes.

TABLE B

Approx. High Tension Transformer Output Voltage	Diameter of Hole in Inches
10,635	0.0024
12,980	0.0025
15,350	0.0026
17,715	0.0027
20,100	0.0028
22,450	0.0026
24,800	0.0027
27,200	0.0028
29,550	0.0027
31,900	Flashed and Burned

The lenses here had a thickness of 0.22 mm. as against 0.025 mm. in the previous set, but as explained hereinafter this slight difference in thickness is not material. Otherwise the operating conditions were unchanged from those obtaining in Table *A* and again the results indicate no significant variation in aperture size with change in voltage.

It will be noted, however, that there is a difference in the average size or diameter of the holes between the two groups of lenses reported in Tables *A* and *B*, the holes in Table *B* being substantially smaller than those in Table *A*. This arises from the fact that in perforating the lenses in Table *A*, a transformer of higher current capacity was employed. The effect of current on the size of the aperture is further illustrated in Table *C* where a comparison is made using, in one set of lenses, a current limiting resistor 92 (see Fig. 8) of ten thousand (10K) ohms inserted in the high tension lead to one of the electrodes and, in a second set, no resistor and the lower capacity (10kv., 24.2 ma.) transformer.

TABLE C

Lens Sample	Diameter of Hole Produced in Inches	
	With Current Limiting Resistor	Without Current Limiting Resistor
1.	0.0018	0.0022
2.	0.0020	0.0023
3.	0.0017	0.0024
4.	0.0018	Flashed and Burned

The same voltage (approximately 16,525 volts) was employed throughout this series. The lens thickness was 0.22 mm. and the time interval was again 0.02 second, in all examples.

Other tests have shown that varying the high tension voltage using the current limiting resistor produces no significant change in the diameter of the hole, at least within voltage limits which do not result in burning or cracking at the peripheries of the holes. However, the range of suitable voltages is somewhat narrower in this case than where no resistor is used although the quality or physical characteristics are improved.

The length of time during which the perforating voltage is applied to the electrodes is also material to the quality of the hole produced in the lens; i.e., the uniformity, shape, lack of cratering, cracking or burning around the hole, and general smoothness of the bore produced are dependent on the time interval. But again, within the useful limts, variations in the time of current discharge do not appreciable affect the size or diameter of the hole. This is illustrated in Tables *D* and *E* at a constant discharge voltage but for transformers to two different current ratings. In Table *D*, the indicated results were obtained at 16,525 volts using a transformer rated at 60 milliamperes at 15,000v.; no current limiting resistor was used and the lens samples all were 0.23 mm. thick. Satisfactory holes were produced in time intervals of from around 0.02 up to about 0.40 second. Greater times tended to cause surface irregularities and burning while shorter times did not consistently effect penetration.

TABLE D

Lens Sample	Time (seconds)	Diameter (inches)
1.	0.02	0.0032
2.	0.05	0.0031
3.	0.10	0.0032
4.	0.15	0.0033
5.	0.20	0.0036
6.	0.25	0.0035
7.	0.30	0.0038
8.	0.35	0.0030
9.	0.40	0.0035
10.	0.45	0.0033

TABLE E

Lens Sample	Time (seconds)	Diameter (inches)
Series I		
1.	0.02	0.0026
2.	0.05	0.0027
3.	0.10	0.0028
4.	0.15	Flashed
5.	0.20	0.0028
6.	0.25	Flashed and Burned
Series II		
7.	0.02	0.0020
8.	0.05	0.0019
9.	0.10	0.0024
10.	0.15	Flashed and Burned

In Table *E*, the voltage was also held at 16,525 v. but the transformer was of lower nominal capacity, being rated at 24.2 milliamperes at 10,000 v. In Series I, in this table, the lenses were perforated without using a current limiting resistor; in Series II, a 10K resistor was inserted in series in the electrode circuit. In this case, satisfactory holes were not produced when the time interval exceeded 0.02 second, as burning began to be quite evident beyond this point.

The effect on the diameter of the hole where the thickness of the lens is varied is shown in Table *F* under conditions of constant voltage and time interval.

TABLE F

Lens Sample	Thickness (mm)	Diameter (inches)
Series I		
1.	0.23	0.0033
2.	0.22	0.0034
3.	0.20	0.0030
4.	0.19	0.0035
5.	0.15	0.0033
Series II		
6.	0.26	0.0028
7.	0.24	0.0037
8.	0.21	0.0030
9.	0.19	0.0027
10.	0.07	0.0028

In Series I, "HyFrax" lenses were used having an optical density of 1.53. In Series II, the lenses were "PMMA" type having an optical density of 1.49. Both of these are methyl methacrylate polymers. Thus it appears that thickness of the material within the range normally encountered in opthalmic lenses does not significantly affect the size of the hole produced, nor does moderate change in density of the lens material.

The amount of pressure of the electrodes on the lens prior to discharge of the current which forms the perforations is important. Too light a pressure may result in a hole which is not straight, or it may cause the current to flash along the surface of the lens. On the other hand, too great a pressure of the electrodes on the lens will cause the point of the electrode to penetrate the surface of the lens and distort it by making a depression. As illustrated schematically in Fig. 6, the apex of the point on the tip 33 of the electrode is for practical reasons larger than the diameter of the hole to be perforated. Consequently, if too great a pressure is applied by the electrode, the point will form a depression in the lens surface which is larger than the hole. This forms a bevelled intersection of the hole with the lens surface, which is highly undesirable insofar as porous contact lenses are contact lenses are concerned. In such applications, therefore, the pressure of the electrodes on the lens must be carefully chosen. In the examples set forth hereinbefore, about an eigth of an ounce pressure has been found to be satisfactory. Other materials, however, will undoubtedly require different pressure settings.

It has also been found that pre-ionizing the material to be perforated produces improved results in that the holes are of more consistently higher quality. Preionization is accomplished by producing a voltage at the electrodes of about half the final voltage determined for piercing a hole of desired size. This is done just prior to the application of the regular penetrating voltage, and the pre-ionizing current is generated for the same time interval as that required for final penetration. From limited tests performed, it is believed that preionization in this manner has little or no effect on the size of the hole produced. It does, however, improve the surface qualities and sharpness of the hole and, while not always essential pre-ionizing has been found to produce more uniform perforations.

WHAT WE CLAIM IS:—

1. The method of electrically perforating dielectric materials which comprises applying a pair of electrodes to the surface of the workpiece at the points between which a perforation is required, exerting a predetermined mechanical pressure on the workpiece through the electrodes, fixing each of the electrodes in position, and then discharging an electric current between the electrodes for a predetermined interval of time through the workpiece in order to form a hole of desired diameter therein.

2. The method according to claim 1 wherein the hole has a diameter of a size measured in thousands of an inch.

3. The method according to claim 1 or 2, wherein one of the electrodes is brought into contact with the workpiece first in order to fix the workpiece in its work-holder and then the other electrode is brought into contact with the opposite side of the workpiece, the pressure applied by the other electrode being no greater than that applied by the first.

4. The method according to claim 1, 2 or 3 wherein the piercing operation is performed within a liquid of high dielectric strength.

5. The method according to any of claims 1 to 4 which includes the further steps of controlling the current of the electrical discharge in order to produce a hole of predetermined diameter.

6. The method according to any preceding claim of electrically percing contact lenses of polymerized methyl methacrylate having a thickness of from about 0.10 mm. to 0.30 mm. which comprises applying a potential across the electrode gap of from about 3,000 to 25,000 volts for a period of time from about 0.02 to 0.30 seconds.

7. The method according to claim 6, which comprises applying a reduced potential to the electrodes prior to applying the full piercing potential thereto.

8. Apparatus for piercing a workpiece of dielectric material and of relatively thin cross-section comprising a work-holder for positioning the workpiece, an electrode mounted relative to the work-holder for engagement with one side of a workpiece supported thereon, means for urging the electrode and workpiece into engagement with each other with a predetermined force, means for locking the electrode against movement toward the workpiece, and means for passing an electrical current discharge from the electrode through the workpiece for a predetermined time-interval in order to perforate the workpiece.

9. Apparatus according to claim 8 which includes a second electrode disposed on the opposite side of the workpiece from the first electrode, means for urging the second electrode into engagement with said workpiece under a predetermined pressure, and means for locking the second electrode against movement toward the workpiece.

10. Apparatus according to claim 9 in which both electrodes engage the workpiece along a line which is normal to a surface of the workpiece.

11. Apparatus according to claim 10 wherein the electrodes are provided with conical work-engaging tips the axes of which coincide.

12. Apparatus according to claim 9 wherein the electrodes are arranged vertically and the work-holder is adapted to support the work-

piece with its surface disposed substantially horizontally.

13. Apparatus according to claim 12 including means for submerging the workpiece in a dielectric fluid.

14. Apparatus according to any of claims 8 to 13 including an electrical control circuit for limiting the discharge voltage and time of discharge of said high potential current.

15. The method of piercing small-diameter holes in dielectric materials substantially as hereinbefore described.

16. Apparatus for perforating a workpiece dielectric materials substantially as hereinbefore described with reference to the accompanying drawings.

17. An article when pierced by the method claimed in any one of claims 1 to 7.

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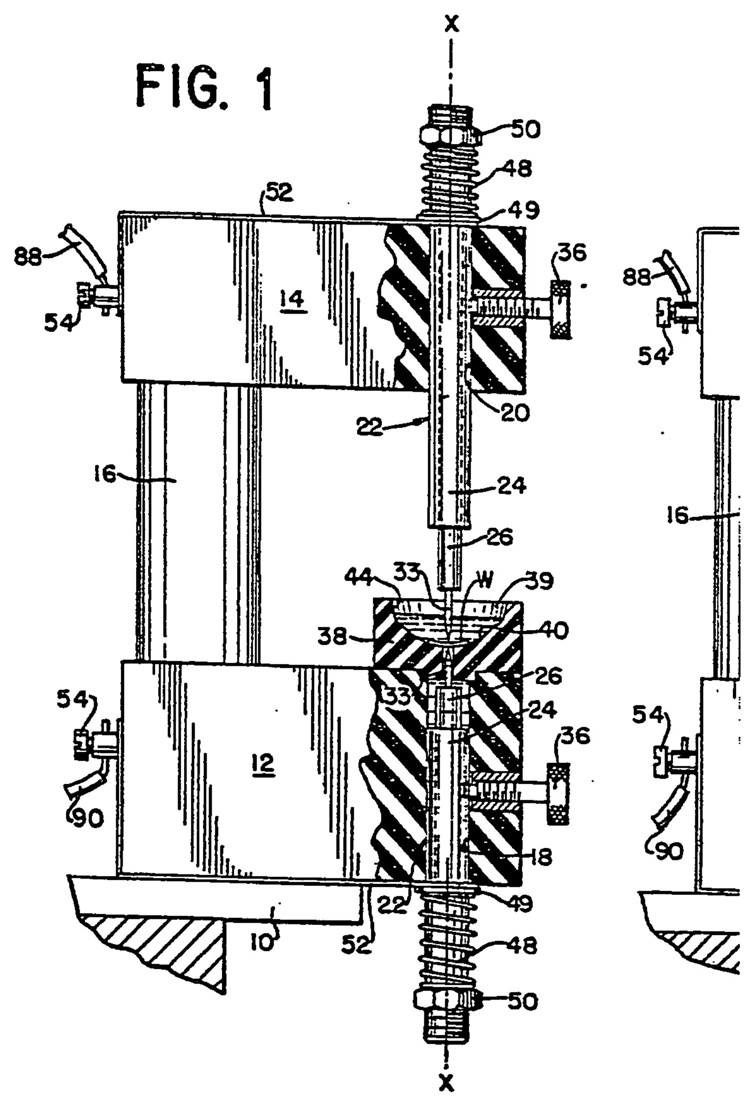
FIG. 1



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1089369 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

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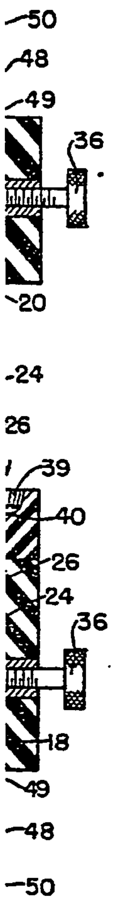


FIG. 2

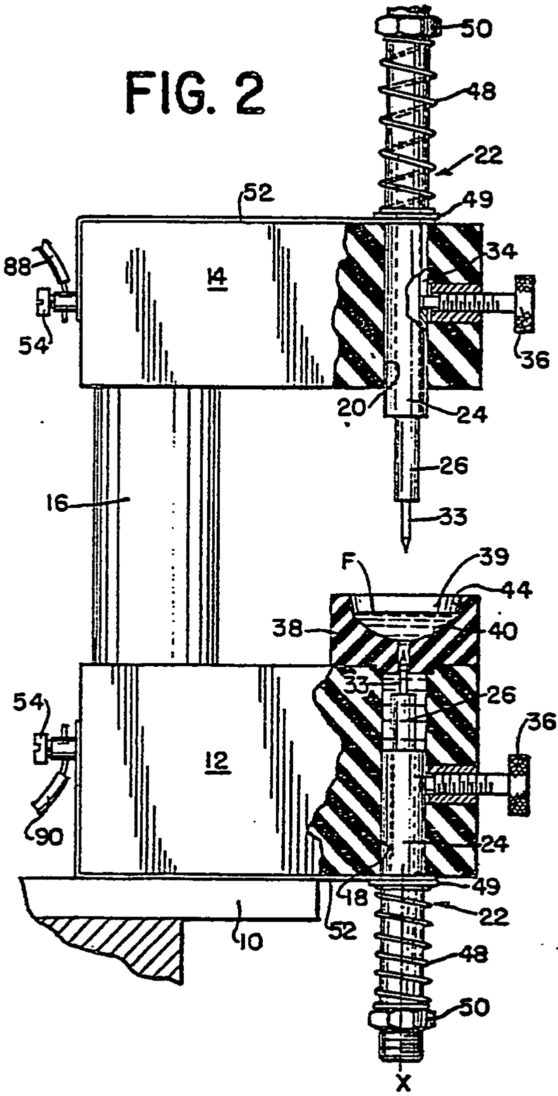
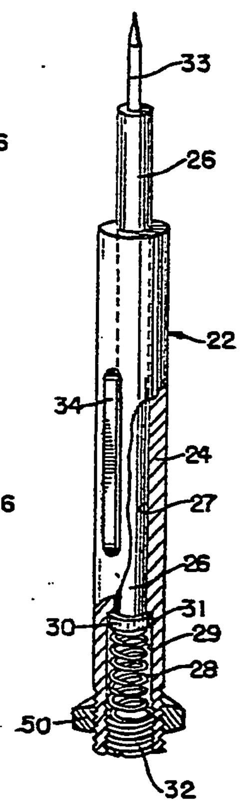


FIG. 3



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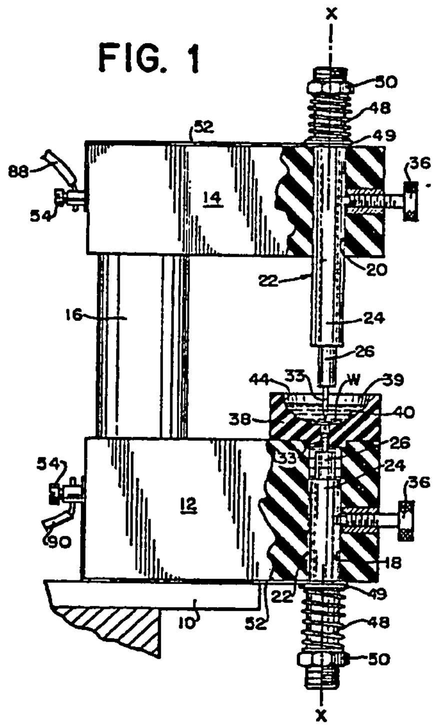
Sheet 1

FIG. 1



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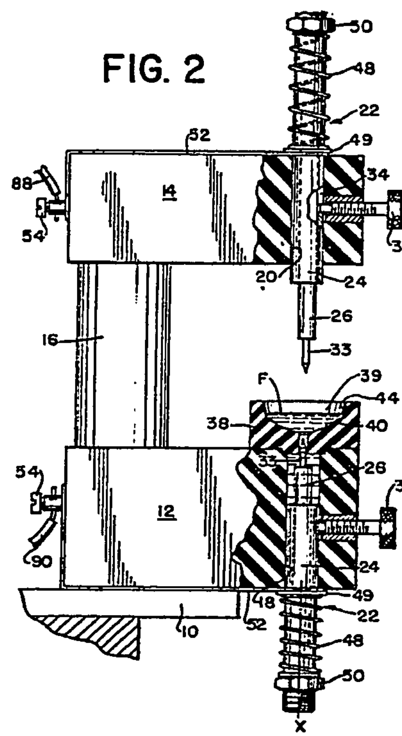

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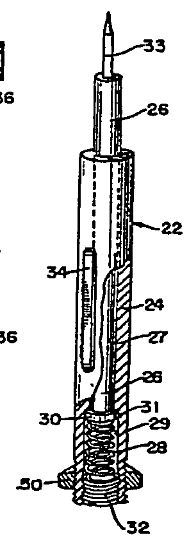
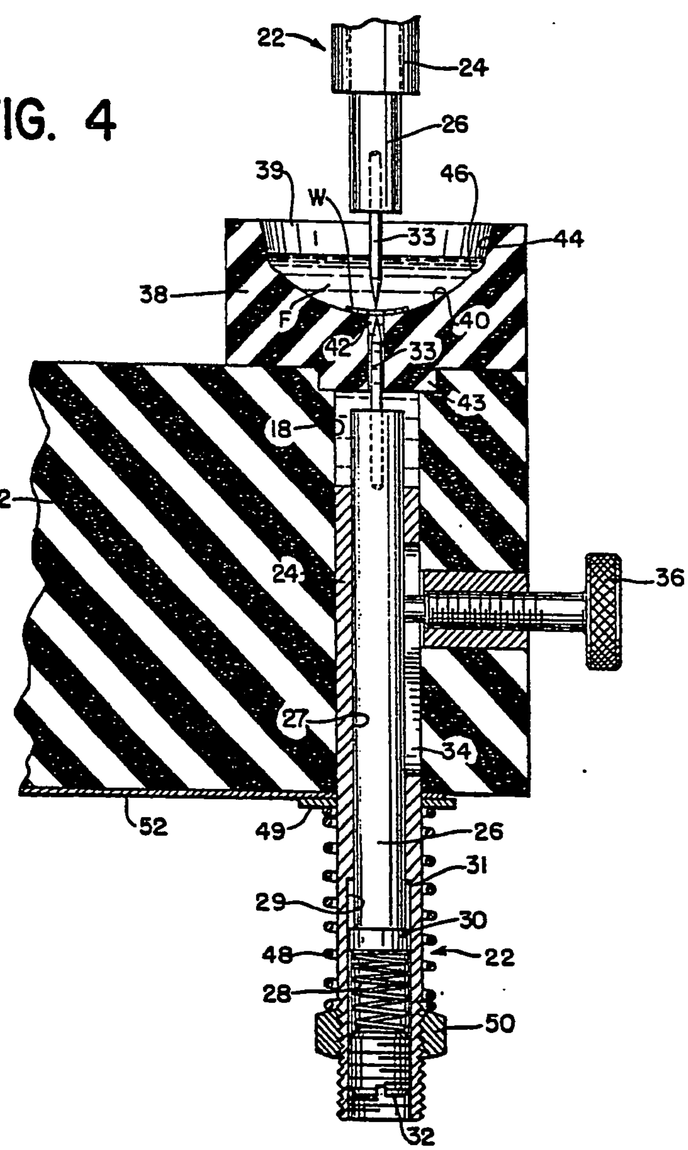


FIG. 4



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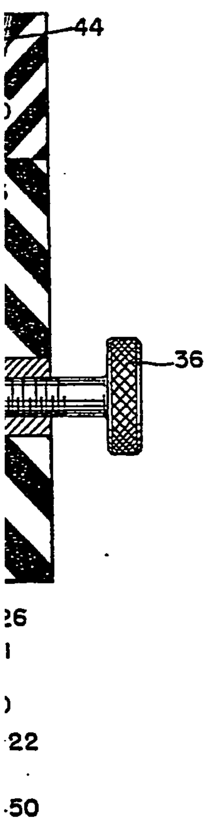

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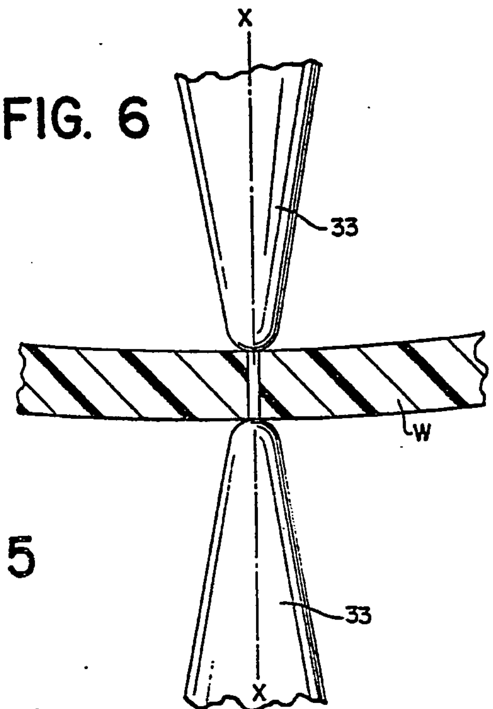

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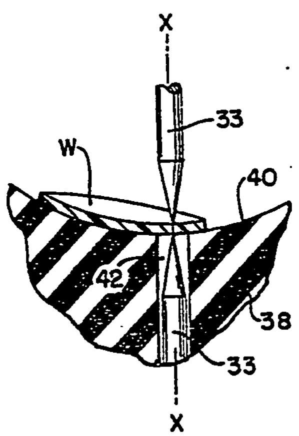

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FIG. 4

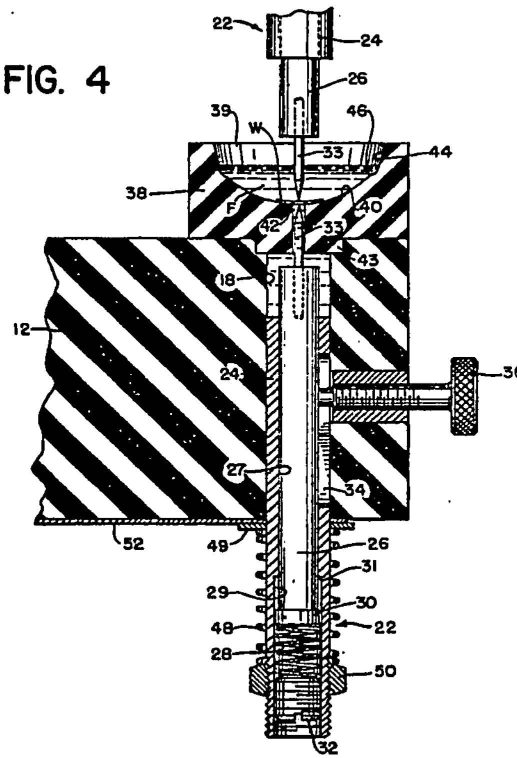
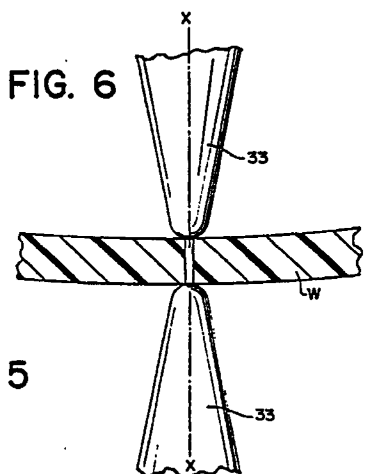


FIG. 6



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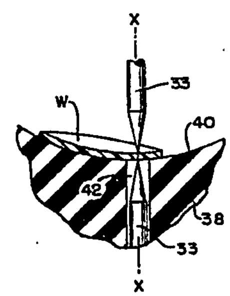

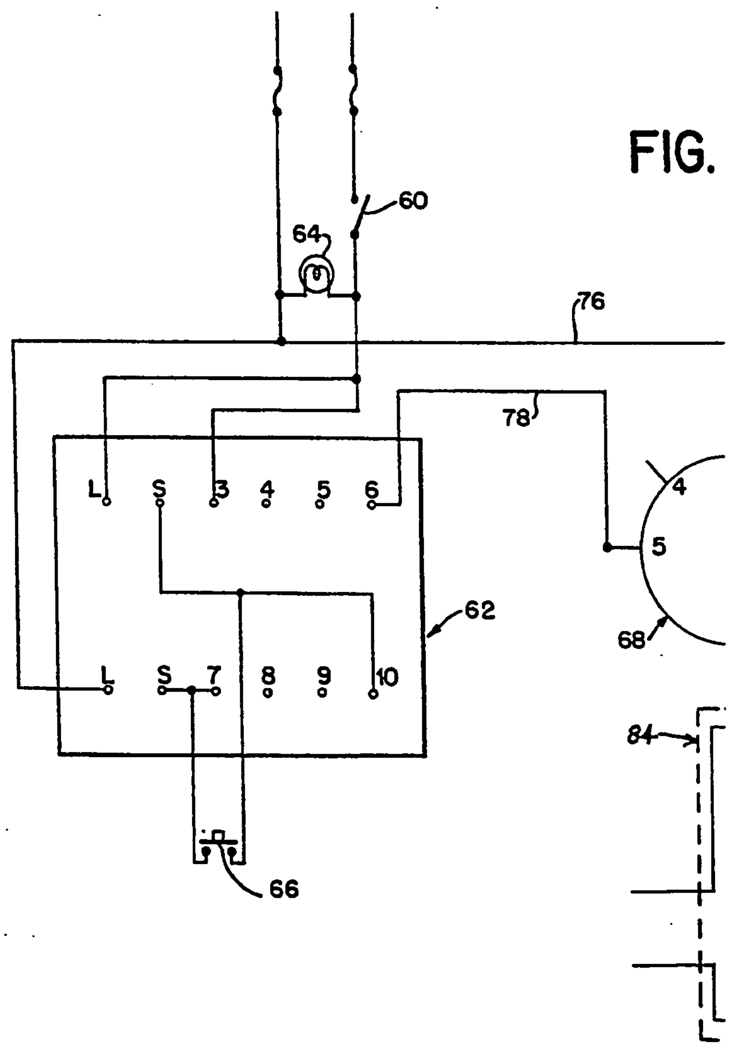

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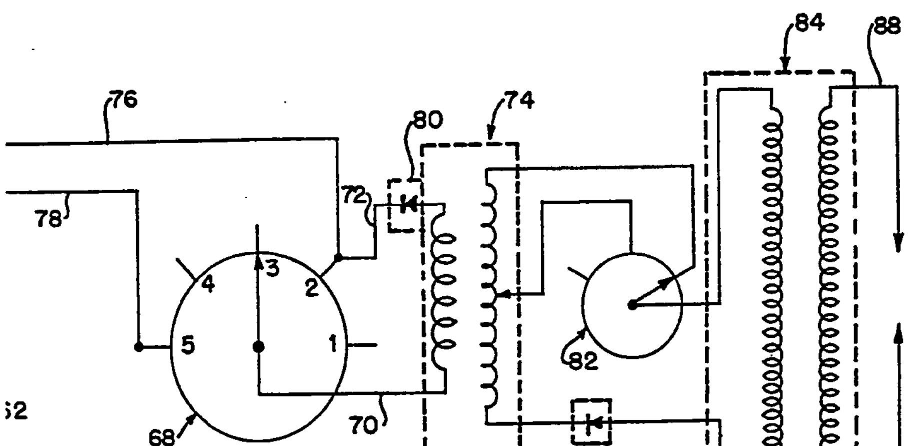
FIG. 7



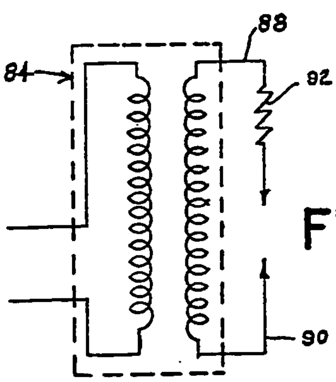


FIG. 8

FIG. 7

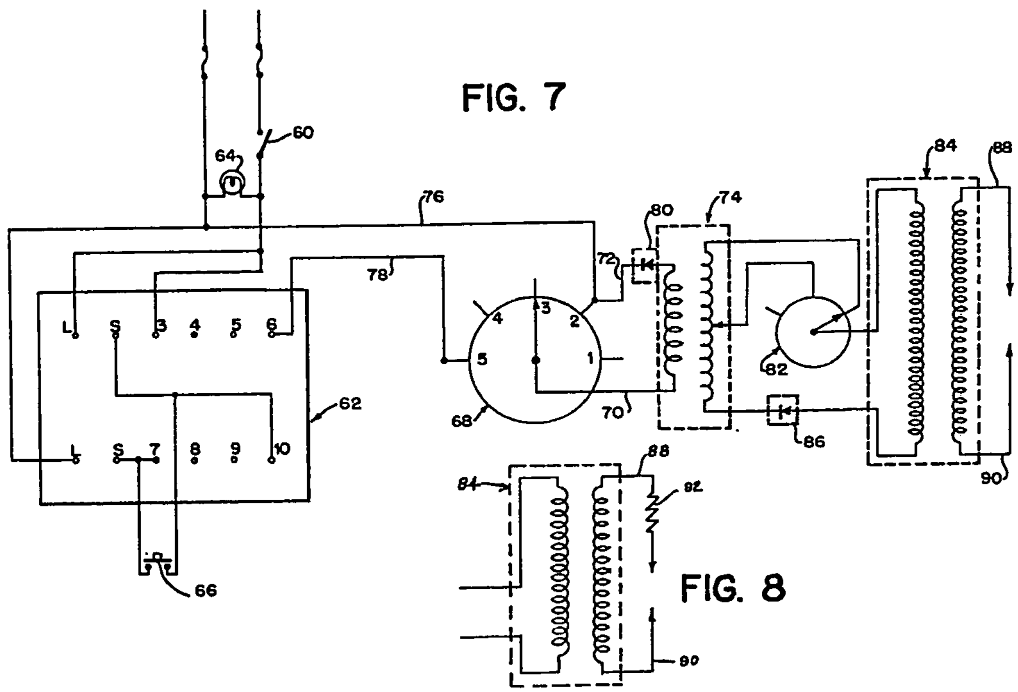

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FIG. 8